IMAGING LENS

BACKGROUND OF THE INVENTION

Recently, digital cameras have become very popular, along with personal computers that process image information from imaging systems. More compact and less expensive digital cameras and imaging systems are being demanded, and these demands have been addressed by

5   developing more compact and less expensive imaging lenses. For example, Japanese Laid-Open Patent Application 2000-258684 discloses an imaging lens that includes, in order from the object side, a negative lens element and a positive lens component with a sufficient back focus distance, with a short focal length, and with at least one lens surface of the negative lens element being an aspheric lens surface. However, the imaging lens of this published Japanese application is not

10   sufficiently compact. Greater compactness, as well as a more inexpensive imaging lens, is needed.

Previously in digital cameras, it has been necessary to use small optical elements that allow a principal ray to enter at an angle of incidence within about fifteen degrees to the normal of the imaging plane because of the light detecting properties of the image pickup elements used

15   with the imaging lens. Recently however, the use of principal rays with angles of incidence larger than about fifteen degrees have become acceptable with some image pickup elements now available. Accordingly, the development of an imaging lens that is capable of correcting aberrations with the principal ray having a larger angle of incidence is desired.

20   ## BRIEF SUMMARY OF THE INVENTION

The present invention relates to a fixed focus imaging lens that is compact, is of inexpensive construction, favorably corrects aberrations, and is particularly designed for use in digital cameras and imaging systems used with personal computers and portable electronic equipment.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will become more fully understood from the detailed description given below and the accompanying drawings, which are given by way of illustration only and thus are not limitative of the present invention, wherein:

5   Fig. 1 shows a cross-sectional view of the imaging lens according to Embodiment 1;

Fig. 2 shows a cross-sectional view of the imaging lens according to Embodiment 2;

Figs. 3A - 3C show the spherical aberration, astigmatism, and distortion, respectively, according to Embodiment 1; and

Figs. 4A - 4C show the spherical aberration, astigmatism, and distortion, respectively,

10   according to Embodiment 2.

DETAILED DESCRIPTION

First, definitions of the terms "lens element" and "lens component" that relate to the following detailed description will be given. The term "lens element" is herein defined as a single transparent mass of refractive material having two opposed refracting surfaces, which

15   surfaces are positioned at least generally transversely of the optical axis of the imaging lens. The term "lens component" is herein defined as (a) a single lens element spaced so far from any adjacent lens element that the spacing cannot be neglected in computing the optical image forming properties of the lens elements or (b) two or more lens elements that have their adjacent lens surfaces either in full overall contact or overall so close together that the spacings between

20   adjacent lens surfaces of the different lens elements are so small that the spacings can be neglected in computing the optical image forming properties of the two or more lens elements. Thus, some lens elements may also be lens components. Therefore, the terms "lens element" and "lens component" should not be taken as mutually exclusive terms. In fact, the terms may frequently be used to describe a single lens element in accordance with part (a) above of the

25   definition of a "lens component."

A general description of the preferred embodiments of the imaging lens of the present

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invention will now be described with reference to Fig. 1 that shows Embodiment 1. In Fig. 1, the lens elements are referenced by the symbols L_1 and L_2, in order from the object side of the imaging lens. Similarly, the radii of curvature of the refractive optical elements are referenced by the letter R followed by a subscript denoting their order from the object side of the imaging lens,

5   from R_1 to R_6. The on-axis surface spacings (along the optical axis X of the figures) of all the optical surfaces are referenced by the letter D with a subscript denoting their order from the object side of the imaging lens, from D_0 to D_5.

In accordance with the definitions of "lens component," and "lens element" above, in the two preferred embodiments of the imaging lens of the present invention described below, lens

10   elements L_1 and L_2 are also lens components. Thus, the present invention may variously be described in terms of lens elements or in terms of lens components. For simplicity of explanation, the following descriptions of the present invention refer generally to lens elements. However, these descriptions apply more generally also to lens components for which the lens elements are examples. Additionally, when the lens components may include more than one lens

15   element, lens elements, as well as the lens components, may satisfy the following descriptions, as appropriate.

As shown in Fig. 1, an aperture diaphragm 2 that operates as an aperture stop is arranged on the object side of the first lens element L_1. That is, the aperture diaphragm 2 is arranged nearer the object side within the imaging lens. A collimated beam that is parallel to the optical

20   axis X is converged to the position P, and a cover glass 1 is positioned on the image side of the second lens element L_2 with one surface thereof including the position P. Entrance surfaces of image pickup elements (not shown) may be located at the surface which includes the position P.

The first lens element L_1 has positive refractive power and a meniscus shape with its concave lens surface on the object side, and the second lens element L_2 has positive refractive

25   power and a meniscus shape with its convex lens surface on the object side. The curvature of field of the image surface can be favorably corrected by making the first lens element L_1 of a meniscus shape with its concave lens surface on its object side and the second lens L_2 of a

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meniscus shape with its convex lens surface on the object side. Additionally, aberrations can be corrected extremely well by making both lens surfaces of both the first lens element L_1 and the second lens element L_2 of aspheric shape. Even if only one lens surface of each of the first lens element L_1 and the second lens element L_2 is of aspheric shape, aberrations can be corrected

5   relatively well.

Additionally, the concave lens surface of the second lens element having a meniscus shape is formed so that its negative refractive power increases as the distance Y from the optical axis X increases, which assists in correcting the curvature of field of the image surface.

For lens surfaces that are aspheric, the lens surfaces are described by the following

10   equation:

$$Z = [(CY^2) / \{1 + (1 - K \cdot C^2 \cdot Y^2)^{1/2}\}] + A_3 Y^3 + A_4 Y^4 + A_5 Y^5 + A_6 Y^6$$
$$+ A_7 Y^7 + A_8 Y^8 + A_9 Y^9 + A_{10} Y^{10} \quad \ldots \text{Equation (A)}$$

where

Z is the length (in mm) of a line drawn from a point on the aspheric lens surface at a

15   distance Y from the optical axis to the tangential plane of the aspheric surface vertex,

C is the curvature ($= 1$ / the radius of curvature, R) of the aspheric lens surface near the

optical axis,

Y is the distance (in mm) from the optical axis,

K is the eccentricity, and

20   A_3 - A_{10} are the third through tenth aspheric coefficients.

Further, preferably the following condition is satisfied:

f1 / f2 < 3.0   . . . Condition (1)

where

f1 is the focal length of the first lens element L_1, and

25   f2 is the focal length of the second lens element L_2.

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If Condition (1) is not satisfied, it becomes difficult to correct the curvature of field of the image surface.

Additionally, preferably the following condition is satisfied:

$$C_{L2} / D_{L2} > 0.8 \qquad \ldots \text{Condition (2)}$$

where

C_{L2} is the thickness of said second lens component, measured parallel to the optical axis, at a distance from the optical axis determined by the smaller maximum optically effective diameter in said imaging lens of the two lens surfaces of said second lens component, and

D_{L2} is the thickness of the second lens component at the optical axis X.

As shown in Figs. 1 and 2, C_{L2} is a distance, as measured parallel to the optical axis, from a point at the periphery of the optically effective area of the lens surface of the second lens element L_2 that has the smaller maximum optically effective diameter in said imaging lens to the other lens surface of the second lens element L_2.

Condition (2) above controls the shape of the second lens element. If Condition (2) is not satisfied, it becomes difficult to correct distortion and curvature of field while providing a sufficient distance to the exit pupil.

Two preferred embodiments of the imaging lens of the present invention will now be described with reference to Figs. 1 and 2.

Embodiment 1

Fig. 1 shows a cross-sectional view of the basic lens element configuration of the imaging lens of Embodiment 1. Table 1 below lists the surface number #, in order from the object side, the radius of curvature R (in mm) of each surface near the optical axis, the on-axis surface spacing D (in mm), as well as the refractive index N_d and the Abbe number ν_d (both at the d-line of $\lambda = 587.6$ nm) of each optical element for Embodiment 1. Listed in the bottom portion of Table 1 are the focal length f, the f-number F_{NO}, and the maximum image angle 2ω.

TABLE 1

#	R	D	N_d	ν_d
0 (stop)	∞	0.25		
1*	-1.4813	1.10	1.50614	56.4
2*	-1.3948	0.10		
3*	1.2881	1.10	1.50614	56.4
4*	1.7046	1.67		
5	∞	0.80	1.51680	64.2
6	∞			

$$f = 2.75 \text{ mm} \qquad F_{NO} = 4.0 \qquad 2\omega = 63.8°$$

The surfaces with a * to the right of the surface number in Table 1 are aspheric lens surfaces, and the aspheric surface shape is expressed by Equation (A) above.

Table 2 below lists the values of the constants K, A_4, A_6, A_8, and A_{10} used in Equation (A) above for each of the aspheric lens surfaces of Table 1. Aspheric coefficients that are not present in Table 2 are zero. An "E" in the data indicates that the number following the "E" is the exponent to the base 10. For example, "1.0E-2" represents the number 1.0×10^{-2}.

TABLE 2

#	K	A_4	A_6	A_8	A_{10}
1	-8.3450	-3.1124E-1	-1.1619E-2	6.0955E-2	2.0131E-2
2	1.0557	-7.0484E-4	-9.7380E-3	-2.6776E-2	-7.5055E-3
3	2.9314E-1	2.7421E-2	-2.0416E-2	2.0119E-2	-5.3439E-3
4	1.5493E-1	1.2355E-1	1.5674E-2	1.2923E-2	3.3139E-3

Embodiment 1 satisfies Condition (1) with the value of f1 / f2 being equal to 1.62. Embodiment 1 also satisfies Condition (2) with the value of C_{L2} / D_{L2} being equal to 0.99. Fig. 1 illustrates the distance C_{L2}, and the distance D_{L2} is the distance illustrated in Fig. 1 as D_3.

Figs. 3A - 3C show the spherical aberration, astigmatism, and distortion, respectively, of the imaging lens according to Embodiment 1. In Fig. 3A, the spherical aberration is shown for the d-line (λ = 587.6 nm), the g-line (λ = 435.8 nm), and the C-line (λ = 656.3 nm). As shown in Fig. 3A, the f-number is 4.00. In Fig. 3B, the astigmatism is shown at the d-line (λ = 587.6 nm) for both the sagittal image surface S and the tangential image surface T. In Fig. 3C, the

distortion is shown at the d-line ($\lambda = 587.6$ nm). The half-image angle ω for Figs. 3B and 3C is 31.9°.

As is clear from the lens data and aberration curves discussed above, in Embodiment 1 the various aberrations are favorably corrected.

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Embodiment 2

Fig. 2 shows a cross-sectional view of the basic lens element configuration of the imaging lens of Embodiment 2. Table 3 below lists the surface number #, in order from the object side, the radius of curvature R (in mm) of each surface near the optical axis, the on-axis surface

10   spacing D (in mm), as well as the refractive index N_d and the Abbe number ν_d (both at the d-line of $\lambda = 587.6$ nm) of each optical element for Embodiment 2. Listed in the bottom portion of Table 3 are the focal length f, the f-number F_{NO}, and the maximum image angle 2ω.

TABLE 3

#	R	D	N_d	ν_d
0 (stop)	∞	0.05		
1*	-6.2341	1.10	1.50614	56.4
2*	-1.4222	0.25		
3*	10.3042	1.10	1.50614	56.4
4*	∞	1.59		
5	∞	0.80	1.51680	64.2
6	∞			

f = 2.89 mm F_{NO} = 4.0 $2\omega = 63.6°$

The surfaces with a * to the right of the surface number in Table 3 are aspheric lens

25   surfaces, and the aspheric surface shape is expressed by Equation (A) above.

Tables 4 below lists the values of the constants K, A_4, A_6, A_8, and A_{10} used in Equation (A) above for the aspheric lens surfaces #1 and #2 of Table 3, and Table 5 below lists the values of the constants K and A_3 - A_{10} used in Equation (A) above for each of the aspheric lens surfaces #3 and #4 of Table 3. Aspheric coefficients that are not present in Tables 4 and 5 are zero. An

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"E" in the data indicates that the number following the "E" is the exponent to the base 10. For example, "1.0E-2" represents the number 1.0×10^{-2}.

TABLE 4

#	K	A_4	A_6	A_8	A_{10}
1	-300.0	-1.4137E-1	1.1724E-1	6.8958E-2	1.7474E-2
2	2.5855	4.1107E-1	-4.9092E-1	3.6650E-1	1.9335E-1

TABLE 5

Aspheric Factor	#3	#4
K	-27.6694	300.0
A_3	9.9562E-3	-2.3320E-2
A_4	5.7773E-1	2.1545E-1
A_5	-5.5167E-1	6.5725E-3
A_6	5.0935E-2	-1.5041E-1
A_7	8.4760E-2	1.1021E-1
A_8	1.6604E-2	4.9791E-2
A_9	1.8845E-2	-4.7642E-2
A_{10}	-2.9601E-2	-9.7171E-3

Embodiment 2 satisfies Condition (1) with the value of f1 / f2 being equal to 1.62. Embodiment 2 also satisfies Condition (2) with the value of C_{L2} / D_{L2} being equal to 0.99. Fig. 2 illustrates the distance C_{L2}, and the distance D_{L2} is the distance illustrated in Fig. 2 as D_3.

Figs. 4A - 4C show the spherical aberration, astigmatism, and distortion, respectively, of the imaging lens according to Embodiment 2. In Fig. 4A, the spherical aberration is shown for the d-line (λ = 587.6 nm), the g-line (λ = 435.8 nm), and the C-line (λ = 656.3 nm). As shown in Fig. 4A, the f-number is 4.00. In Fig. 4B, the astigmatism is shown at the d-line (λ = 587.6 nm) for both the sagittal image surface S and the tangential image surface T. In Fig. 4C, the distortion is shown at the d-line (λ = 587.6 nm). The half-image angle ω for Figs. 4B and 4C is 31.8°.

As is clear from the lens data and aberration curves discussed above, in Embodiment 2 the various aberrations are favorably corrected.

The invention being thus described, it will be obvious that the same may be varied in many ways. For instance, values such as the radius of curvature R of each of the lens elements and components, the surface spacing D, the refractive index N_d, as well as the Abbe number ν_d, are not limited to the examples indicated in each of the aforementioned embodiments, as other

5   values can be adopted. Additionally, the shape of the aspheric lens surfaces may be varied. Also, lens elements that act as lens components may variously be modified as lens components that include more than one lens element. Thus, the descriptions of imaging lenses of the present invention above, including the descriptions of Conditions (1) and (2) above, may be similarly expressed in terms of lens components or in terms of both lens components and lens elements, as

10   appropriate. Furthermore, the invention may be used with digital cameras, personal computers, and a variety of portable electronic devices. Such variations are not to be regarded as a departure from the spirit and scope of the invention. Rather, the scope of the invention shall be defined as set forth in the following claims and their legal equivalents. All such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following

15   claims.